Water Quality Management Practices

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Lecture - 23

Coagulation

Hello everyone, welcome to this NPTEL online certification course on Water Quality Management Practices. My name is Gourav, Professor Gourav Dhar Bhowmick from the Department of Agriculture and Food Engineering of Indian Institute of Technology, Kharagpur. So, in this particular lectures lecture material, we will be discussing about the coagulation which is a part of the module 5, Physiochemical Operations and Processes II. These are the concept that I will be covering the properties of colloidal solid particles, surface charge, electrical double layer, zeta potential and psi potential, particle stability, theory of coagulation, type of coagulants, governing parameters and some numerical worked examples. To start with we all know that the primary sedimentation is one of the crucial process in for removing the settleable suspended particles and to prepare the effluent for the secondary treatment processes right. So, in this sedimentation efficiency it normally depends on the size and the nature of this settling solids.

The larger particles settle through the gravity settling in plane sedimentation process. If you can see this table, it nicely like you know demonstrates. So, what are the type of solid materials and what are the size typical size range that can be used for removing like you know for which kind of processes we can use to remove those type of particle sized like pollutant from the waste water. To start with if you have a large floating matter like more than 6 mm size range, it will be easily removed by coarse cream.

If it is like 2 to 6 millimeter, we can remove it by fine screen. If it is a grid particle, if you remember we already designed it. So, in this grid particle the sand and silt which is of more than 0.2 millimeter can be easily removed by the grid chamber. Then we have the suspended organic matter which we already know and we designed also that it is has a it has a particle size of around more than 0.

1 millimeter, it can be easily removed by the gravity settling process in the sedimentation time primary sedimentation time. Then we have the colloid particles. If we have a colloid particles like 0.001 to 1 micron that is what our target is. In this particular lecture, we will be discussing majorly about the this colloid particles which are very hard to remove.

So, for that we need we use the coagulation flocculation and the sedimentation process. And then there comes a dissolved solids for that we go for the biological treatment or sometimes the membrane processes as well like we when the size range will go below then 0.001 micrometer. In general, what is colloid particles? Colloid particles majorly it has a certain similar surface charge because of that what happened they continuously repel each other. And because of that you will see a Brownian motion that is it is if you if you know about this Brownian motions, it know about the coagulants and I mean know about the colloid and all.

So, in colloid particles they demonstrate a very distinct feature which we call the Brownian motions because they are constantly repelling each other and constantly they are moving around in the so, in this colloid solution. And because of that it we cannot easily make it agglomerate or like make it agglomerate and sedimented on the bottom. It needs some certain specific I mean like I mean like you know uses of some kind of chemicals, some kind of mechanical processes also sometimes we can use, but mechanical plus chemical is one of the best one ok. So, in general this mechanical chemical process normally we follow this coagulation flocculation and the sedimentation we will discuss about that only in this particular lecture that how this colloid particles can also be removed from the wastewater. In general the coagulants or the flocculants it is aids in added to the neutralizing the surface charge and by neutralizing the surface charge it destabilize the colloidal particles.

So, once this majorly most of the colloidal particles in general in when we discuss when you will see it is majorly constitutes of the negatively charged particles on its surface. So, this if we somehow you neutralize somehow can neutralize that charge what will happen? It will start agglomerating with each other and then once it is the size of this floc is big enough it start settling due to the gravity settling processes. So, this is what our target is here in the coagulation process ok. What are the basic properties of colloidal solid particles? If you see in general the undissolved solids in the wastewater it can be settled by suspended solid process I mean like suspended if it is a suspended solid it is can be removed by gravity settling, but if it is a colloidal solid we have we need some coagulants for this for the removal for neutralizing the surface charge and all. So, this coagulation flocculation process and normal normally we employ for destabilize the colloidal solid and to enhance the removal efficiency this colloidal solid can be hydrophilic or hydrophobic ok.

So, hydro means water right and it means the water affinity. So, the hydrophilic means it is it is I mean like there are two types of things this water affinity was if we talk about then hydrophobic means like you know it repel water it does not like water kind of for some phobia. So, and this philic means it is a it is attract water. So, I mean like it is it normally form some like you know hydration layer and form some water surrounding layer on its surface. This hydrophobic colloid in normally it lack the significant affinity for water and in majorly the inorganic colloid like the clay particle falls into this category.

However, the water soluble groups of hydrophilic colloid like amino, carboxyl and all. So, they normally promote this hydration and you see this pictures they form this machine like formation or the bilayer you see this hydrophilic head it normally attracts the water it stays along with the make a water surrounding layer. So, when we destabilize the hydrophilic colloid. So, it is much more challenging than the hydrophobic ones. So, the clay particles and all if it is there in the in your sample in your waste water or in your water sample it is much more easier for you to like you know get rid of it by using a very low coagulant doses.

But hydrophilic ones because it makes this water surrounding layer it is much more difficult you need to increase the doses to in order to get rid of in order to get rid of the charges that the surface charges that it presents in its outer layer. In general there are how they develop the surface charges first is isomorphous replacement. Ions in the lattice structure of colloid are replaced by the similar run of lower valency. What do I mean by the lower valency? See in this particular example we have a aluminum 3 plus and the silicon 4 plus. So, in case of aluminum 3 plus if it is it replace the silicon 3 plus in a solid SiO 4 crystal which makes the entire lattice negatively charged as ai 3 plus it has a less one less valence electrode then the Si 4 plus and because of that it creates a charge imbalance as one oxygen atom it remains the unpaired and because of that when whenever the aluminum 3 plus ion enters this crystal lattice it becomes it there is this isomorphous replacements is happening.

This preferential or the selective adsorption this inert particle like silica oil droplet oil droplets or what happened what they allow the anions like the hydroxyl groups or the hemi hemiic acid or the dye to attach to its surface and hence acquire a net negative charge on the surface of it. This is another way of how the colloid get the charges. Secondly, third is the structural imperfections. What happens sometimes the mineral crystals the charge can developed in its imperfect layer or there are some cavities there are some cleavages on its of bonds because of that the in the age it there is a chances of a huge amount of ion depositions. Negatively negatively charged ion deposition can happen.

Then the ionization it actually depends on the pH. The dissociation of compounds such as the hydroxyl group, carboxyl group, amino group it occurs depending on the pH of the wastewater and because due to the gain or loss of proton and based on the pH available pH of the ambient pH of the solution. For instance silica if you see this sample silica like having this hydroxyl group on its exterior surface at its different charge depending on the pH of the solutions. If it is less than 2 pH if you see this OH 2 plus if you have this around 2 pH its SiOH and then its more than much more than 2 pH its SiOH negative.

$$-Si-OH_2^+ \leftrightarrow Si-OH \leftrightarrow Si-OH^-$$

$$pH<<2.0 \qquad pH=2.0 \qquad pH>>2.0$$

So, this is how they acquired the negatively charged I mean like this colloid particles they acquired their surface charges.

So, in general the surface charge allow this colloidal particle to remain in suspension for extended time period without aggregating because they are keep on repelling each other and they are they are showing this Brownian motion. The development of the surface charge depends upon the composition of the medium as well and the nature of the colloid and for majority of the colloid particle present in the wastewater the surface charge is negative ok. So, here I would like to like you to understand of a very basic understand basic funda about the electrical double layer that forms around the colloidal surface. If you see this colloidal surface is negatively charged colloidal surface is yellow color just right next to it there is this dense positive ions deposited right. So, because of obviously, because of they attract each other.

So, this dense positive layer its right next to it you will see another layer where the positive amount of positive ion is much less than the dense ones. And then there comes the another phase the third phase where you see that there are comparatively similar amount of positive and negative ions are present surrounding to the system surrounding to the structure. So, the first one if you see the dense positive ion if you see that area we normally have this we call it the stern layer and right next to it you have this you see this plane of shear after the plane of shear you see the diffuse layer ok. So, that is why it is called the electrical double layer the stern layer and the diffuse layer. So, how if you see the right side graph right now there if you see this this electrical double layer total the distance is total distance is showcase and also in actually in the y axis it it showcases the distance from the particle surface and in the x axis it showcases the electrostatic potential.

If you see how much of the electrostatic potential that you have to overcome to make that that colloidal particle to neutralize that colloidal particle it is given in this graph. So, if you see the difference between the electrical double layer from its from its surface to the surface of the colloidal particle to the diffuse layer the end of the diffuse layer you will see that particular potential difference is called as high potential that is the total potential that it requires. If you see the only the shear plane of shear to the diffuse layer only in order to overcome the diffuse layer if you see that potential is called the zeta potential. So, and another stern potential is also called stern potential is the one where the from the stern layer to the until the diffuse layer. So, this gap it is the is represented by the stern potential and all.

So, you have to understand this zeta potential, stern potential and the psi potential ok, that in order to overcome or you have to apply in in a in such a way the so, that that you will reach to the you will somehow neutralize the colloidal particles present in present in your waste waters ok. So, in general the inner layer it comprises of positively charged counter runs adsorbed over the negatively charged surface they normally adsorbed because of the forces of because of the forces forces like van der Waals forces of attraction and also the electrostatic forces of attraction which are strong enough to resist the thermal agitations as well. And the thinner outer diffuse layer with a stretch of this this stern layer it has a like you know the how to say the stretch of about 0.5 nanometer and the diffuse layer the outer one that I was discussing. So, it lies beyond the stern layer and has partially distributed ions and it can extend up to 30 nanometer as you can see from the graph also it goes up to 0.

5 to 30 nanometer in the in the y axis if you see. So, this is in general this is how it looks like in a and this is this concept is called the electrical double layer and which actually hinders the transportation of the colloidal dispersion in a any solution. So, this zeta potential and this psi potential. So, electrophoresis normally it occurs when the electric current is applied to an electrolyte solution with charge particles. Zeta potential is the electrical potential between the

cloud surface or the plane of shear and the bulk solution during the electrophoresis if you remember in the last slide only we discussed and the psi potential is what is the potential drop between the colloidal surface and the bulk solution.

So, bulk solution is beyond the double layer electric beyond the double layer you will find the bulk solution. So, this bulk solution and the potential drop between the colloidal surface is called the psi potential. In general the coagulation effectiveness is observed within a zeta potential range of point plus minus 0.5 millivolt with the zeta value 4 pi Q d by epsilon. So, here if you see this Q value is a charge per unit area and d is the thickness of the layers surrounding to the shear surface of the particles through which the charge is effective and the sigma is the dielectric constant of the liquid medium.

So, in general colloidal solutions in which particles remain in suspension without aggregating under natural condition are referred to as the stable suspension ok. And the stability of this colloidal particle in wastewater is mainly due to the force of electrostatic repulsion which counter balances the Van der Waals forces of attraction between them and is also referred to as the electrostatic stability ok. So, what are the factors which affect the colloidal particle stability? First is the force of electrostatic repulsion ok, second is the concentration of colloid the amount of colloidal particle per unit volume is based on that the pH of the suspension as I was discussing and also the addition of external destabilizing compound. The more destabilizing compound you introduce it will make it more disperse into this liquid and into the suspension into the solution and it will be very difficult for us to actually make it agglomerate and settle on the in any treatment unit. In general if we discuss about the theory of coagulation so, how it actually forms in general the coagulation we consider it as a chemical process by in which the destabilization of colloidal particle happens by addition of suitable coagulant ok.

So, normally we use alum, alum is the most famous one all of you know that alum is a very useful coagulant that we normally use and also hydrated aluminium or the hydrated aluminium sulphate and the ferric chloride is also another famous coagulant that we normally use. So, what happen when we introduce this alum or the ferric chloride into the wastewater or say water where there is a chances of having a huge number of huge amount of colloidal particles. So, what happen this we normally destabilize this colloid which leads to the increment in the size of the agglomerate particles which ultimately favors the settling of those from the water or wastewater due to the forces of gravity ok. The increase in size occurs due to the particle collision and which happens when the charge of the particle is neutralized. So, as they allow the particle to come sufficiently close enough for the Van der Waals force to dominate and leading to the agglomerate.

So, first the first the instead of electrostatic repulsion when we change when we convert their like when we neutralize their surface charge what happen they try to come together come near to each other and then the because of the as you know that very tiny particle when they are very close to each other there is a very strong force which we call Van der Waals force which comes into the action. This Van der Waals force is very strong. So, when this tiny particles are very atomic size particles when they are like almost near to each other they experience this Van der

Waals force because of this Van der Waals force they started agglomerating with each other and after a while it has enough weight. So, that you will it will start the mass will become enough that it will start sedimenting on the bottom because of the forces of the gravity ok. So, how it happens when normally electrical double layer contraction is happens second is the adsorption of the charge or the charge neutralization if you can see in the left side picture ok.

So, we first do the charge neutralization you see the negatively charged colloid particles we introduce the positively positive ions and this positive ions making it neutralizing the neutralizing the surface charge of the colloidal particles. Then will be the sweep coagulations when they started coagulating with each other they started feeling this Van der Waals force as I was mentioning and then the inter particle particle bridging or the adsorption of the inter particle bridging process where they started making a long chain polymers and this at the end it started settling on the bottom. So, what are the types of coagulant those are normally used first is the polyvalent metallic salt like alum as I was mentioning, copper or the hydrated ferrous sulphate, chlorinated ferrous sodium aluminate different kind of polymers are also there like ionized group like amino sulphonic or the carboxyl group, cationic like containing the positive groups and the anionic which contains negative group. You may surprised like how anionic groups can also be useful it is also useful at a certain extent and the ampholytics are also useful like which has both positive and the negative groups. When we select a coagulant what are the properties that we normally try to you know have it in our coagulant what about the dosing that we are doing.

The first thing it should have a it should produce high charged species in water that carries the effective coagulations reducing the net total suspended solid concentration in the turbidity. It should not produce any toxic intermediates that means, like when it is introduced to your system to your water body it reacts with the colloidal particles anionic should not come up with some byproduct or some intermediate products which can be toxic in nature. So, definitely then the effluent will be unfit for the discharge or reuse. So, that is why you have to make sure that this toxic intermediates are not present there. It should have no or less solubility for a pH range in which water or wastewater treatment is carried out and what are the different governing parameters for the coagulations.

The first is the alkalinity. The formation of the sticky gelatinous metal metallic hydroxide precipitates which is essential for an effective coagulation process is only possible when the alkalinity is properly maintained in your solution in the solutions I mean like where the you are treating you are introducing the coagulants. Second is the pH. pH it really plays a vital role in this production of the precipitates found by the trivalent metallic coagulants which is responsible for this coagulation. The dosing of coagulant it is very important you have to find out the optimum dosing for your coagulants to come up with first of all it is economically viable, second is so, it will not make some additional pressure to the follow up systems because of the additional coagulant which may present there in the system can also problematic for further biological treatment processes or any other tertiary treatment processes that you are adhering in your treatment unit. Also the rapid mixing that is very important that it is not only the doses of coagulant that it important that it is important obviously, but one of the major how to say the like the parameter which actually represents which actually governs that your the coagulant dosing will actually work properly that is the rapid mixing.

So, rapid mixing has to be there should be some mechanical mixer or some agitation devices by which you do a rapid mixing of your system. It should not be for long it can be for as little as a one minute, but that duration of mixing has to be provided. So, this in general what is the temporal mean velocity of mixing that is required it is represented by

$$G = \sqrt{\frac{P}{\mu V}}$$

So, this p is the power applied to the shaft in watt, μ is the dynamic viscosity of the wastewater in Newton second per meter square and the V is the volume of the tank in meter cube. So, from this equation we can actually find out the minimum energy that it requires or threshold energy that we need to provide and the temporal mean velocity for like you know for the mixing processes to happen.

In general this flash mixer I use if you see in this picture we have this electrical motor in the bottom we have this impeller shaft and the impeller. This impeller started rotating at a high speed and when we introduce the coagulant from this coagulant feed if you see and the influent is actually there is a baffle wall. So, this baffle wall what is the need of this baffle wall? It is baffle is to break the vortex motion formation to ensure the proper mixing. So, because in general impeller is causing the vortex motion right, but the baffle walls are actually breaking those vortex motions and make it more the mixing possible more I mean like not I would say like I would I cannot say the homogeneously, but it makes it more effective for actually for the coagulant dosing to happen and actually it reacts with the colloidal particle more efficiently ok. So, this is this kind of this system is called the flash mixture.

So, if you see if you go to any treatment plant and all. So, when they were whenever they use this coagulant dosing if you see they normally use this flash mixers and all it is quite widespread there you will see a lot of people use it in their treatment plants and all ok. In general the retention time is very important. So, in usual practice it stays somewhere between ranges somewhere between 30 second to 2 meter 2 minute with a typical design value of 60 second as I was mentioning. So, what are the governing parameters for this coagulation coagulant dose? So, for optimum doses of coagulant it is determined experimentally by using a test called jar test.

So, you may suppose you have one like 6 different type of jar as it is shown in this picture. So, in this 6 different jars it has say like some exact volume of wastewater sample wastewater. Now, you put them you provide different doses of alum at a same pH level. So, what you can do you can first you can carry out the test you can carry out in a various pH level of wastewater ok. Then at a constant coagulant dose and then you determine the best turbidity in a optimum pH.

Once you know the optimum pH now you use that pH and use different dosing and try to find out that which particular dose of alum is the best. So, first you have to find out the optimum pH then you have to find out the optimum alum dosing ok. So, in order to make sure that your that your alum dose is just sufficient enough for getting rid of or actually to incorporate all the colloidal particles present there and it turbidity remains as minimum as possible. I mean like the turbidity the final turbidity will be as low as possible. How turbidity is actually playing the major role here because see turbidity in ethanometric turbidity unit NTU when we when we carried out what does that mean? Turbidity it actually showcases that in a amount of fuzziness, amount of solid particles present in your system.

So, the more clean it is the turbidity when it becomes much lesser so that means, that there is a there is a possibility that the all those colloidal particles are actually started settling down ok. So, it gives you a direct indication of your you know effectiveness of your alum dose and all effectiveness of whatever coagulant that you are targeting this is very useful ok. So, please remember that we normally before going to actual scenario in the real field scenario when whatever coagulant you will choose you have to do the jar test first. In the jar test at if you see there is a mixture also if there is a small mixture from the top it keeps on rotating.

So, this test is very important ok. So, here using this test you can find out the optimum pH and the optimum coagulant dosing. So, in general what we understood from this lecture material we understood that the coagulation process it is a chemical destabilization of colloidal particle in water or wastewater using the coagulant that increase the particle size and it promotes the settling. The mechanism of coagulation includes the electrical double layer contraction, adsorption and the charge neutralization, adsorption and the inter particle bridging and the swipe coagulation also we understood. We understand that two major types of coagulants are metallic salt and the polymers used in the wastewater or water treatment and alum reacts with the alkalinity to form sticky gelatinous precipitate while polymers reduce the sludge production. The governing parameter for coagulations are alkalinity, pH, rapid mixing and coagulant dosing ok.

And the presence of carbonate, bicarbonate ions and also the dissolved gases contributes to the alkalinity and adding to the formation of sticky gelatinous metallic hydroxide precipitates and all. So, that is somehow beneficial for us. The pH it influences the stability of trivalent metallic coagulants affecting the coagulant process coagulation process and the settling rate of this coagulant colloidal particles. Rapid mixing is very important, it ensure that the proper dispersion and the neutralization of colloidal particle is happening, but insufficient coagulant doses results in inadequate treatment while excessive doses may lead to flop re dispersion and increase the increase the turbidity. So, you remember that coagulation dose has to be optimal value standard value.

Any anything ahead of that anything like more than that value can actually lead to flop re dispersion and in it can obviously, increase the turbidity of the solution. So, we have to do the jar test which normally we use to determine the optimum doses and the working pH range of our coagulant in the wastewater we are targeting and all. So, this is how normally we target the this is the coagulant doses that we discuss and understand this basic principles of coagulation process in the wastewater and water treatment scenario. So, I hope you understand the very important information and very important scientific detailing about what how coagulation works and how coagulant works and how we can optimize the dosing and the pH value, how different type of practices are being followed to reduce the turbidity. So, I hope you have some good understanding about this about this topic.

So, these are the references you can follow. Thank you so much, we will see in the next video. Thank you.